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POPULATION AND REPRODUCTIVE ECOLOGY OF THE SMALL-MOUTHED HARDYHEAD *ATHERINOSOMA MICROSTOMA* (GÜNTHER) (PISCES: ATHERINIDAE) ALONG A SALINITY GRADIENT IN THE COORONG, SOUTH AUSTRALIA

by ROBYN L. MOLSHER*, MICHAEL C. GEDDES* & DAVID C. PATON*

Summary

MOLSHER, R. L., GEDDES, M. C. & PATON, D. C. (1994) Population and reproductive ecology of the small-mouthed hardyhead *Atherinosoma microstoma* (Günther) (Pisces: Atherinidae) along a salinity gradient in the Coorong, South Australia. *Trans. R. Soc. S. Aust.* **118**(4), 207-216, 30 November 1994.

Atherinosoma microstoma in the Coorong exhibited a one-year life cycle with multiple spawning over a four month breeding season from September to December. Large numbers of larval and juvenile fish (5-15 mm long) appeared in samples during October and November and grew rapidly over summer, most reaching lengths of 26-35 mm by autumn and 36-45 mm by the following spring. Only one ovary developed in females and this began to enlarge during August when batches of eggs began maturing. Gonosomatic indices also began to increase at this time. Female fish with spent ovaries were first caught in November. The numbers of large hardyheads (> 35 mm) in samples declined in December and January, reflecting post-breeding mortality.

Salinities ranged from 9 to 67 g L^{-1} at Noonameena, the most northerly sampling site, and from 35 to 94 g L^{-1} at Tea Tree Crossing in the southern end of the Coorong lagoon system. High salinities did not have a marked effect on the population ecology or reproductive potential of *Atherinosoma microstoma*. Hardyheads were caught at all sites on all sampling occasions and no marked differences were found in fish size, growth rate, condition or relative batch fecundity for fish caught from different localities along the salinity gradient. Hardyheads were coping well with the high and fluctuating salinities that exist in the Coorong. Significant differences in batch fecundity were found between years, with those in spring 1990 being about half those of 1991, perhaps reflecting differences in food availability. The possible effects of future proposed reductions in salinity for the Coorong on the biology of *A. microstoma* are discussed. Changes in salinity are unlikely to limit the distribution of hardyheads except through possible influences on their food supply.

KEY WORDS: *Atherinosoma microstoma*, Coorong, hardyhead, salinity, reproduction, population biology, fecundity.

Introduction

The Atherinidae (hardyheads) is a widespread family of small fishes that are commonly found in calm, shallow waters and often have short life cycles (e.g. Gon & Ben-Tuvia 1983; Prince *et al.* 1982; Prince and Potter 1983; Potter *et al.* 1983, 1986). Atherinids are often euryhaline but high salinity may affect their population and reproductive biology. For example, suspected dwarfing in the Mediterranean atherinid, *Atherina boyeri*, may be associated with high salinities (Gon & Ben-Tuvia 1983). The North American atherinid, *Atherinops affinis affinis*, spawned in the field at salinities of 72 p.p.t. but the young died within four months (Carpelan 1955). Most fish species in the Laguna Madre of Texas (up to 80 p.p.t.) do not spawn at salinities greater than 45 p.p.t. (Hedgpeth 1967). Generally, high salinities and fluctuations in salinity restrict reproduction in many aquatic animals, affecting both the number of offspring produced and the timing and length of the breeding season (Kinne 1964).

The small-mouthed hardyhead, *Atherinosoma microstoma* (Günther), is found in abundance over a wide range of salinities including estuaries, marine embayments and hypermarine lagoons in south-eastern Australia from the Tuggerah Lakes in New South Wales, southwards and westwards to Spencer Gulf in South Australia (Ivantsoff 1978[1]; McDowall 1980; R. Connolly & G. K. Jones pers. comm.). The maximum sizes approach 90 mm (total length) in Tasmania and 80 mm in Victoria (Cadwallader & Backhouse 1983). The life cycle of *A. microstoma* has been studied in Dee Why Lagoon, N.S.W., where salinities ranged from 3 to 13 p.p.t. (Potter *et al.* 1986). In these estuarine conditions, *A. microstoma* exhibited a one-year life cycle with a four-month breeding season during spring (August to November). Fry entered the trappable population in October, while larger adults rapidly declined in abundance after November. Growth effectively ceased over autumn and winter (April to August).

A. microstoma has been found throughout the Coorong where conditions range from estuarine in the north to hypersaline in the south (Geddes & Butler 1984). Although hardyheads have been caught in the Coorong in excess of 100 p.p.t. TDS (total dissolved solids), equivalent to a salinity of 91 p.p.t., Geddes (1987) has suggested that extremely high salinities

* Department of Zoology, University of Adelaide, South Australia 5005.

[1] IVANTSOFF, V. (1978) Taxonomic and systematic review of the Australian fish species of the family Atherinidae with references to related species of the old world. Unpublished PhD Thesis, Macquarie University.

(>100 p.p.t. TDS) during late summer and autumn may restrict the southerly distribution of these fish in the Coorong in some years. This study takes advantage of the longitudinal gradient of salinity that exists in the Coorong to study the effect of high salinity on the reproductive performance and population structure of *A. microstoma*.

Materials and Methods

The population structure and reproductive biology of hardyheads were studied at five sites within the Coorong: Noonameena, Villa dei Yumpa, Policemans Point, Salt Creek and Tea Tree Crossing (Fig. 1). These sites spanned a 65 km length of the Coorong lagoon system, with Noonameena in the north usually experiencing a lower range of salinities than the other four sites that were farther south (Geddes 1987). The southernmost site, Tea Tree Crossing, was at the southern extremity of permanent water in the Coorong where the highest salinities in the Coorong had been reported.

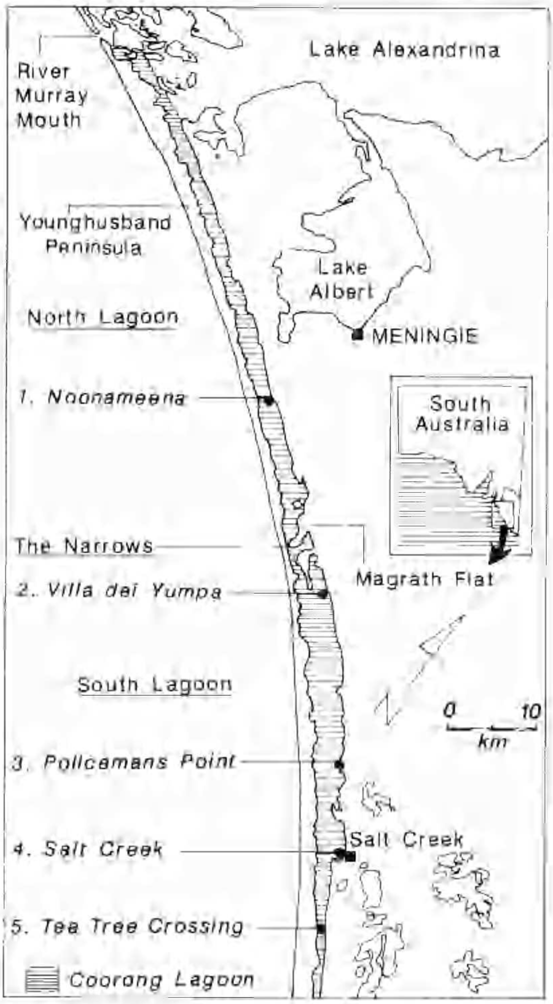


Fig. 1. The Coorong Lagoon showing the five sampling sites.

The salinities and temperatures of the water at each of the sites were measured at monthly intervals between September 1990 and January 1992. Water temperatures were recorded at a depth of 40 cm between 0900 h and 1800 h. Water samples, collected from a depth of 40 cm, were returned to the laboratory and salinities were estimated by measuring electrical conductivities (conductivity meter CDM3) and converting these values to salinities using tables from Williams (1986). Samples with conductivities over 100 mS cm^{-1} were diluted and the calculated salinities multiplied by the dilution factor.

Each month, fish were caught from each site using a 5.5 m long, 1.75 m deep seine net with a mesh size of 1.9 mm. All seining was conducted at a depth of 0.2-0.8 m with hauls over a distance of 40 m. On most occasions a single haul was taken but when the sample contained low numbers of fish (<50), additional seines were undertaken. Successive seines in the one area showed no significant difference in the mean length of fish caught ($t = 1.348$, $N = 200$, $P = 0.179$). Fish traps (63 by 36 by 36 cm, mesh size 1.9 mm) baited with meat (usually chicken) and set overnight in water 0.4-0.8 m deep, were used in the first six months of the study. Traps were expected to catch larger fish, whose superior swimming ability may have enabled them to escape the seine net, and thus provided information on the larger adults in the population. They also provided additional fish for assessing reproductive condition. In addition, a plankton net (350 μm mesh, 60 cm diameter) was hauled through the water (depth 0.2-0.6 m) for two minutes to check for the presence of larval *A. microstoma*. Fish were immediately preserved in 10% buffered formalin and returned to the laboratory where their length and reproductive condition were measured.

The total length (TL-tip of snout to end of caudal fin) of each fish from both the seine and trap samples was recorded to the nearest millimetre using dial calipers. Where the number of individuals was large, a random subsample of approximately 150 individuals was measured. The standard length (SL-tip of snout to posterior edge of the last lateral line scale) of a subsample of fish was measured to determine the relationship between TL and SL, thereby allowing comparisons with other studies. Lengths and body weights of hardyheads caught in October 1990, December 1990 and March 1991 at each of three sites (Noonameena, Policemans Point and Tea Tree Crossing) were measured so that length weight regressions could be calculated. Fish condition was assessed by comparing these length-weight regressions between sites. All length and weight measurements were obtained from fish that had been preserved in 10%

buffered formalin. Sex ratios were calculated for up to 50 hardyheads (>30 mm length) caught in each seine sample from October 1990 to May 1991. The sex of the fish was determined by macroscopic examination of the gonads. Gonads in fish <30 mm had not differentiated clearly and so these fish could not be sexed reliably. Orange coloration of the mid-lateral line and eyes was observed in some fish and the sex of 95 fish that exhibited this coloration was determined.

Seasonal patterns in the reproductive cycle of hardyheads were determined from changes in gonosomatic indices (GSI) and the examination of oocytes in the ovaries of female fish. Male fish were not investigated as preliminary examinations showed no marked changes in gonadal weight. The gonosomatic index (GSI) was calculated by expressing gonad weight as a percentage of body weight (De Vlaming *et al.* 1982). Gonad weight and body weight were measured to the nearest milligram for up to 20 female fish (TL>40 mm) in each sample. Only female fish that were at least 40 mm in length were used in the analysis as the ovaries of smaller fish did not contain maturing oocytes. Ovaries of female fish from three sites (Noonameena, Policemans Point and Tea Tree Crossing) were excised and preserved in modified Gilson's fluid (Puckridge 1988[2]). These ovaries were then teased apart, shaken vigorously, and stored for two weeks to separate the oocytes from the ovarian tissue. Preliminary microscopic examination revealed three different egg types, which parallels the situation found for *Menidia menidia* (Conover 1985). The three general egg types were classified by size (oocyte diameter) and appearance as follows:

1. **immature oocytes:** 0.05-0.70 mm in diameter. The smaller oocytes in this group (0.05-0.22 mm) had a clear cytoplasm and large nucleus, while the larger oocytes (0.23-0.70 mm) were white, opaque and often irregular in shape.
2. **maturing oocytes:** 0.71-1.60 mm in diameter. Spherical and dark yellow in colour.
3. **ripe oocytes:** 1.61-2.50 mm in diameter. Spherical and hydrated with a yellowish yolk centre.

Diameters of oocytes were determined from a single measurement on a random orientation basis (West 1990) using a microscope-video attachment and a digitiser pad downloaded to a computer. Subsequent categorizations of oocytes were based only on appearance. Numbers of maturing and ripe oocytes in ovaries from samples over the two breeding seasons were counted using a stereo-dissecting microscope; immature oocytes were difficult to count and were only counted for samples of fish caught between September

[2] PUCKRIDGE, J. T. (1988) The life history of a gizzard shad, the bony bream, *Nematalosa erebi* (Günther) (Dorosomatinae, Teleosti) in the Lower River Murray, South Australia. MSc Thesis, University of Adelaide. Unpubl.

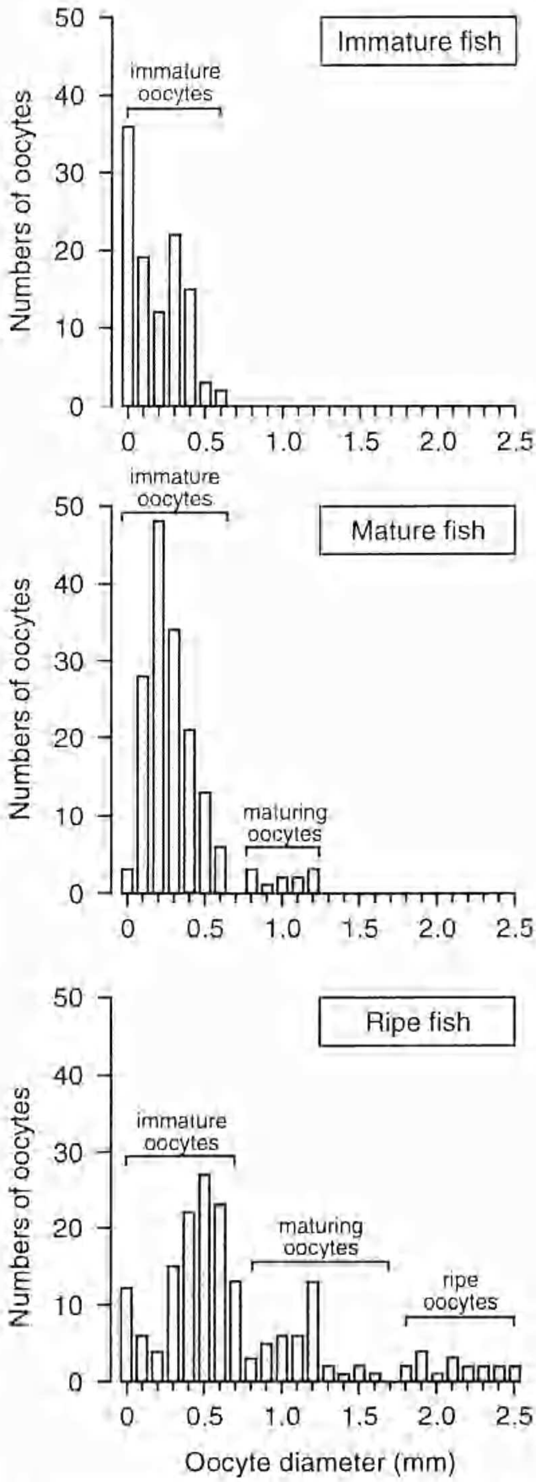


Fig. 2. Frequency of oocyte diameters from the gonads of an immature fish, a mature fish and a ripe fish.

1990 and January 1991. Fish were classified into four stages depending on the type of oocytes present (Fig. 2):
1. **immature fish:** immature oocytes only, firm ovary.
2. **mature fish:** immature and maturing oocytes.
3. **ripe fish:** immature, maturing and ripe oocytes.
4. **spent fish:** maturing or ripe oocytes absent, flaccid ovary.

"Batch fecundity" was defined as the number of maturing oocytes in the ovary and presumably represented the maximum number of oocytes that could be ripened and subsequently spawned at one time. "Relative batch fecundity" was defined as the number of maturing oocytes per gram of ovary-free body weight (Conover 1985). Differences in the fecundity of female fish at different sites in the Coorong were assessed by comparing relative batch fecundities.

Results

Physical Characteristics of the Coorong — September 1990 to January 1992

A longitudinal gradient in salinity persisted in the Coorong with salinities increasing from Noonameena in the North Lagoon to Tea Tree Crossing at the southernmost end of the Coorong (Fig. 3). Hypersaline conditions (>35 g L^{-1}) were maintained at all sites in the South Lagoon, except briefly at Villa dei Yumpa in September 1991. At Noonameena, conditions were estuarine during winter and spring (9-32 g L^{-1}) and generally hypermarine during summer. Seasonal trends were also evident at all sites with salinities high in summer, falling in autumn and rising again in spring. In September 1990, salinities ranged from 32 g L^{-1} at Noonameena to 57 g L^{-1} at Tea Tree Crossing, while in February 1991 salinities had risen to 60 g L^{-1} and 94 g L^{-1} at these two sites respectively. Seasonal changes in salinity were similar in the two years. However, salinities reached their minima earlier in 1991 (August/September) and were lower than in the previous year. Water temperature varied seasonally with maximum water temperatures in excess of 24°C recorded during late summer and minimum temperatures of 11°C in winter (Fig. 3).

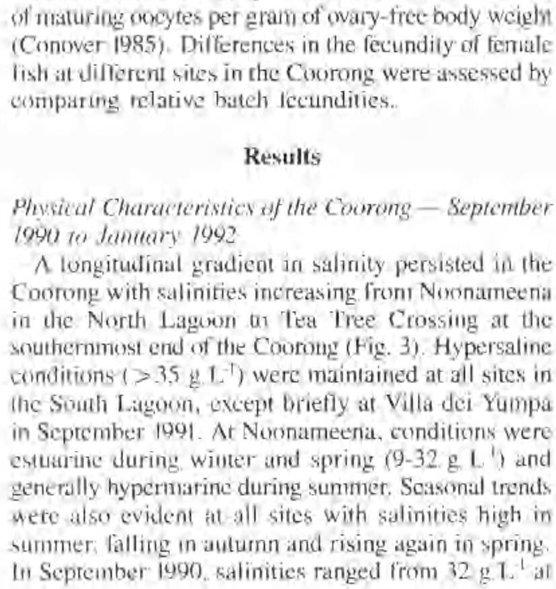


Fig. 3. Seasonal fluctuations in salinity and temperature at five sites in the Coorong Lagoon. Salinities are shown for each site and temperatures are shown as the mean and range for the five sites combined.

Distribution of Fish in the Coorong

Hardyheads were collected from all sites throughout the 17 month period. The highest salinity at which they were found was 94 g L^{-1} (Tea Tree Crossing, February 1991). Five other species of fish were caught commonly, yelloweye mullet (*Aldrichetta forsteri*), congolli (*Pseudaphritis urvilli*), river garfish (*Hyporhamphus regularis*), greenback flounder (*Rhombosolea tapirina*) and blue spot goby (*Pseudogobius olorum*). All species were caught at Noonameena and Villa dei Yumpa where salinities were lower. However, yelloweye mullet was the only species caught with *A. microstoma* at Tea Tree Crossing, and then only during winter and spring. Yelloweye mullet, congolli and blue spot goby were caught at salinities up to 64, 83 and 87 g L^{-1} respectively. Flounder and garfish were caught only at relatively low salinities (<36 g L^{-1}) and only on three occasions. *A. microstoma* far outnumbered other fish species in each sample.

Population Structure of Atherinosoma microstoma *in the Coorong*

The abundance of fish collected at the five sites on the 17 sampling occasions was analysed by two way analysis of variance. The number of hardyheads caught in the first seine for each sample was used in the analysis. There was no significant difference between sites ($F = 0.87$, d.f. $= 79$, $p>0.05$) but there was a highly significant difference between sample dates ($F = 6.03$, d.f. $= 79$, $p<0.001$). Greater numbers of hardyheads were caught during spring and summer. The length frequencies of fish in each sample were inspected and no consistent differences between sites were noted so the sites were pooled for length frequency analysis. The sizes of hardyheads were highly variable at any one time in the year, but there were distinct seasonal patterns (Fig. 4). Larvae and fry (5-15 mm; length class 1 of Fig. 4) were prominent in October, November and December (spring-early summer) of 1990 and 1991. At this time of the year, length-frequency distributions were often distinctly bimodal, consisting of small fish (<25 mm) and larger fish (>35 mm). The 1990 cohort of smaller fish showed a gradual increase in length during summer, reaching lengths of 26-35 mm (length class 3) by May

1991 and 36-45 mm (length class 4) by the following spring (September 1991) at all sites (Fig. 4).

The length-weight relationships for fish collected from Noonameena, Policemans Point and Tea Tree Crossing are shown in Table 1. Statistical comparisons of the slopes by ANCOVA revealed non-significant differences between the sites in December 1990 and March 1991 (Tukey HSD, $p>0.05$). In October 1990, significant differences were found between each of the three sites (Tukey HSD, $p<0.05$), however the assumption of homogeneity of slopes was violated in this month ($F = 5.66$, d.f. = 271, $p = 0.004$). The slopes of the regressions, which indicate relative weights and thus may be interpreted as a "condition factor", showed no consistent relationship with the salinity of the sites (Table 1).

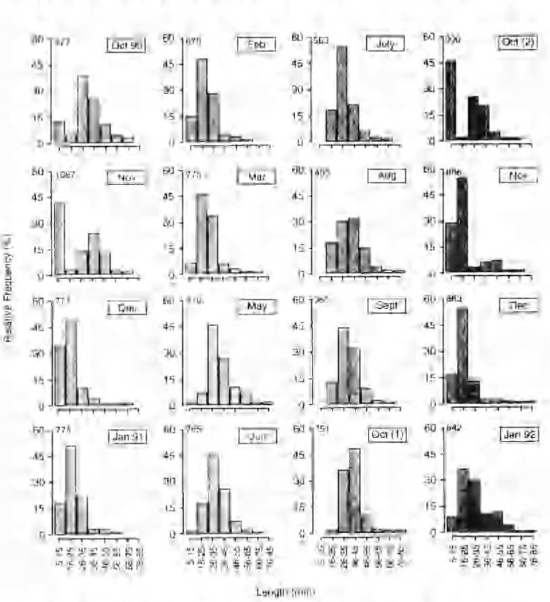


Fig. 4. Relative length-class frequencies of *Atherinosoma microstoma* caught in seine net hauls from October 1990 until January 1992 (two samples 14 days apart were taken in October 1991). Catches from the five sample sites have been pooled as there were no consistent differences between sites in length-class frequencies. The number of fish measured in each sample is indicated at the top left of each distribution.

The length frequencies of male and female fish in the trap and seine samples from all sites combined taken in October 1990, December 1990, March 1991 and May 1991 are shown in Fig. 5. Females were significantly larger than males (independent t-tests, $P<0.05$) in each month. The largest female fish caught in the trap samples was 85 mm (November 1990) while males were below 67 mm (although a single male fish of 75 mm was collected in May 1991). Sex ratios (fish caught in the seine-net only) usually favoured females with significantly more females for all months combined ($\chi^2 = 37.82$, N = 413, $P<0.01$). Orange coloration of the eyes and mid-lateral line was only

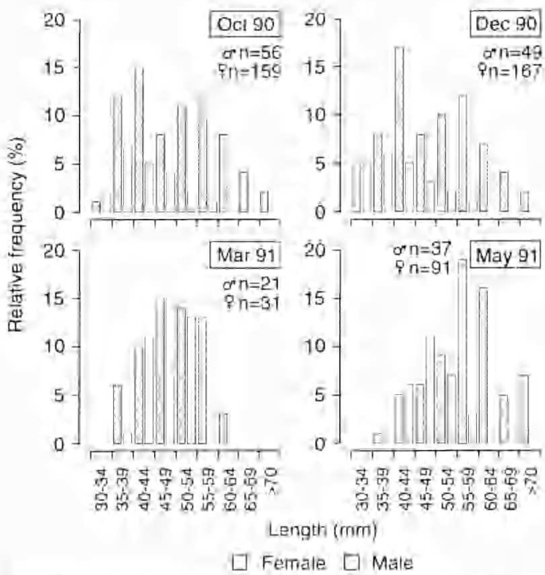


Fig. 5. Relative length-class frequencies for female and male *Atherinosoma microstoma* in October 1990, December 1990, March 1991 and May 1991. For each month fish from trap and seine-net samples were combined.

TABLE 1. *Length weight regressions of* Atherinosoma microstoma *from Noonameena (NM), Policemans Point (PP) and Tea Tree Crossing (TTC) in October 1990, December 1990 and March 1991.*
*Regressions are of the form $Y = aX^b$ where: Y = weight, X = length, a = intercept and b = slope. r^2 = coefficient of determination, n = sample size and *** = $P<0.001$.*

Sample date	Site	a	b	r^2	n
October 1990	NM	9.12×10^{-6}	2.97	0.972***	69
	PP	1.55×10^{-5}	2.79	0.978***	125
	TTC	3.54×10^{-6}	3.12	0.891***	83
December 1990	NM	4.36×10^{-6}	3.12	0.975***	100
	PP	5.75×10^{-6}	3.04	0.969***	100
	TTC	8.13×10^{-6}	2.96	0.966***	100
March 1991	NM	6.03×10^{-6}	3.03	0.939***	100
	PP	8.32×10^{-6}	2.94	0.977***	100
	TTC	7.08×10^{-6}	2.98	0.961***	97

found in male fish over 36 mm TL and only during the breeding season (September-January), indicating that it is related to reproductive behaviour.

The relationship between total length (TL) and standard length (SL) was expressed by the following equation:

$$SL(mm) = 0.61 + 0.85TL(mm)$$
$$(r^2 = 0.99,\ N = 34,\ P < 0.001).$$

Annual Reproductive Cycle of Atherinosoma microstoma *in the Coorong*

Only one ovary developed in female *A. microstoma* and this remained small (<2% of body weight or GSI<2) through autumn and winter in the Coorong (Fig. 6). In spring, the ovaries showed a marked increase in size before declining over summer with similar seasonal patterns occurring at all sites (Fig. 6). The GSIs were highest during September and October in 1991. This annual cycle in reproduction was also reflected in the proportion of immature, mature, ripe and spent fish in the samples (Fig. 7). Female fish possessed only immature oocytes from May to July. Maturing oocytes were first detected in August with large numbers of mature and ripe fish present throughout spring. Spent fish were first detected in November. Some immature eggs remained in the ovary indicating that not all oocytes were matured and shed.

Batch Fecundity of Atherinosoma microstoma *in the Coorong*

The numbers of oocytes, classified as immature, maturing or ripe in the ovary of individual fish collected from the two breeding seasons are shown in Fig. 8. The large variation in numbers of immature oocytes may relate to fish size and to losses due to maturation. There were smaller numbers of maturing and ripe oocytes with most fish having from 5 to 40 maturing oocytes and 5 to 30 ripe eggs in the ovaries.

Batch fecundity (numbers of maturing oocytes) was strongly correlated with ovary-free body weight (r^2 = 0.68, n = 101) in spring 1991 at the time of peak gonad weight (Fig. 9a). Relative batch fecundity (numbers of maturing eggs per gram of ovary free body weight) for fish was independent of ovary free body weight (r^2 = 0.04, n = 101) (Fig. 9b), indicating that

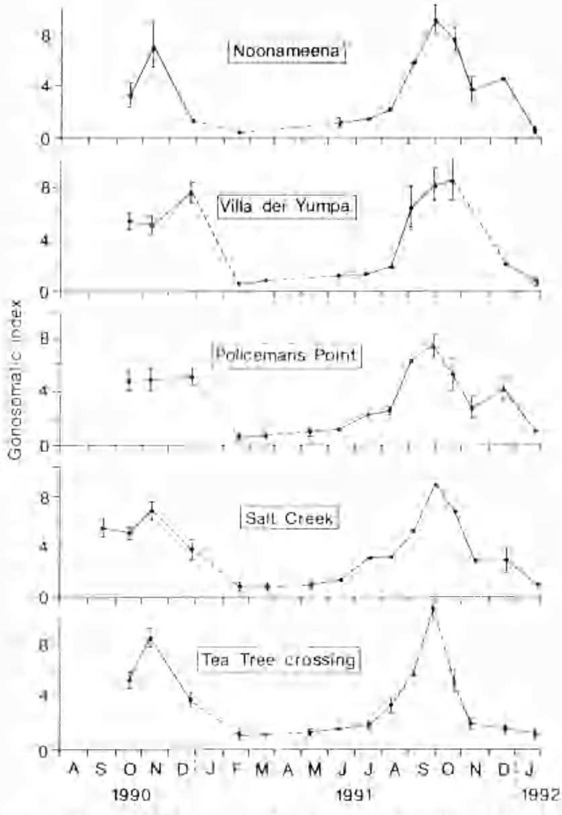


Fig. 6. Seasonal changes in the gonosomatic index of female *Atherinosoma microstoma* at five sites in the Coorong Lagoon. Points represent mean values of up to 20 fish and vertical lines are one standard deviation each side of the mean. No standard deviation is given when sample size was less than 10.

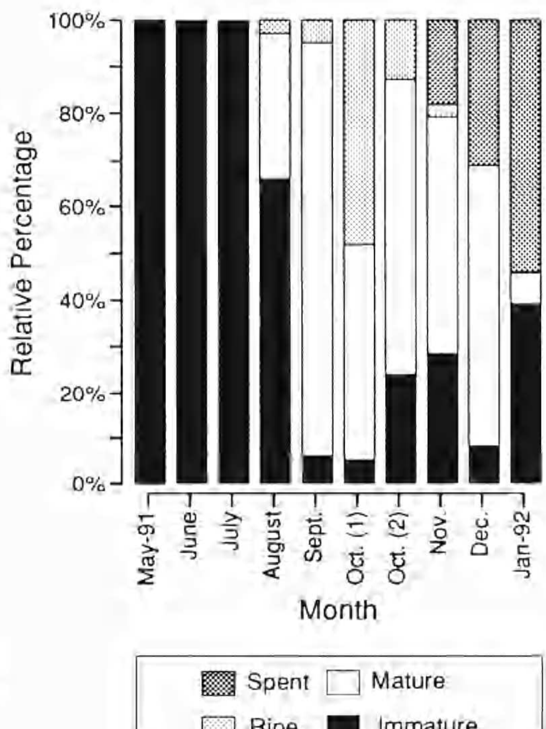


Fig. 7. Relative proportion of female *Atherinosoma microstoma* characterised by the most advanced clutch present in the ovary. Data from all five sites combined.

fish of different sizes were allocating a similar proportion of their resources to egg maturation. Relative batch fecundities (Fig. 10) were not significantly different between sites in spring 1990 ($F = 0.16$, d.f. = 2,45, $P = 0.851$) or 1991 ($F = 3.23$, d.f. = 2,98, $P > 0.05$). However, significant differences were found between years, with relative batch fecundities in 1990 being about half those of 1991 ($F = 51.67$, d.f. = 1,147, $P = 0.001$). The number of maturing eggs per ovary tended to decline after the peak spawning period in October 1991.

Discussion

Influence of Salinity on Distribution, Growth, Size and Condition of Atherinosoma microstoma

Over the summers of 1990-1991 and 1991-1992 the distribution of *Atherinosoma microstoma* in the Coorong was not restricted by salinity. All other fish species appeared to be limited by salinity during the high-salinity summer season in a manner similar to that reported in Geddes (1987) and Geddes & Hall (1990). The highest salinity at which *A. microstoma* was collected was 94 g L^{-1}. This record exceeds the maximum field salinity for this species from coastal salt ponds in Victoria (82 p.p.t., Chessman & Williams 1974). In March 1985, a few individuals of *A. microstoma* were trapped at 149 p.p.t. TDS (salinity approximately 130 g L^{-1}) at Tea Tree Crossing in the Coorong (Geddes 1987; D. C. Paton unpublished). *A. microstoma* ranks along with *Cyprinodon variegatus*, which has been recorded at 142 p.p.t. TDS (Simpson & Gunter 1956), as one of the most salt-tolerant fish species in the world. This ability allows *A. microstoma* to survive at the southern end of the Coorong during extreme hypersaline conditions. Abundance data suggested that hardyhead numbers at the southern sites

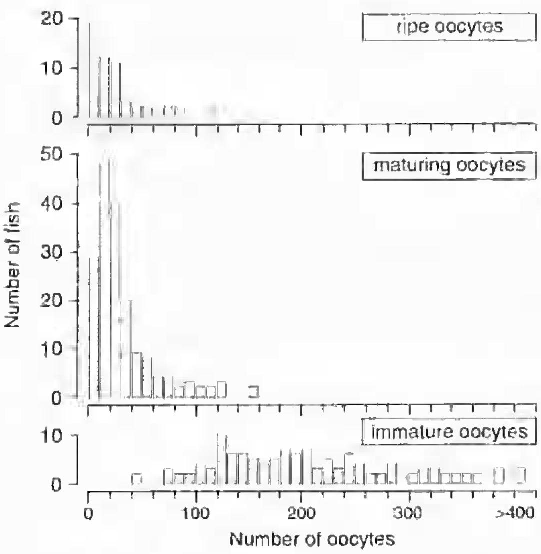
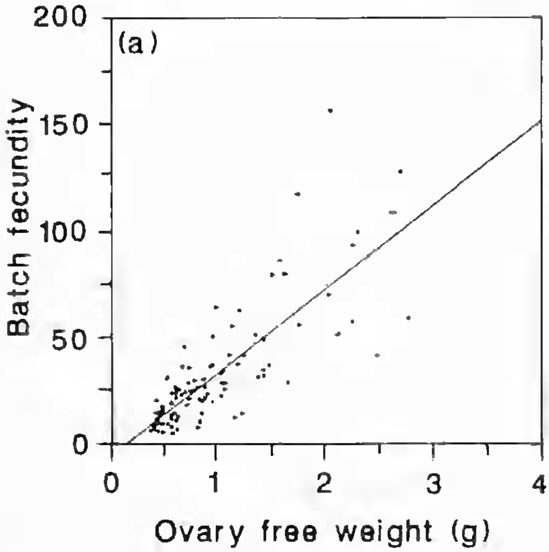


Fig. 8. Frequency distributions of the numbers of immature, maturing and ripe oocytes in the ovaries of female *Atherinosoma microstoma* caught in the Coorong during the 1990 and 1991 breeding seasons.



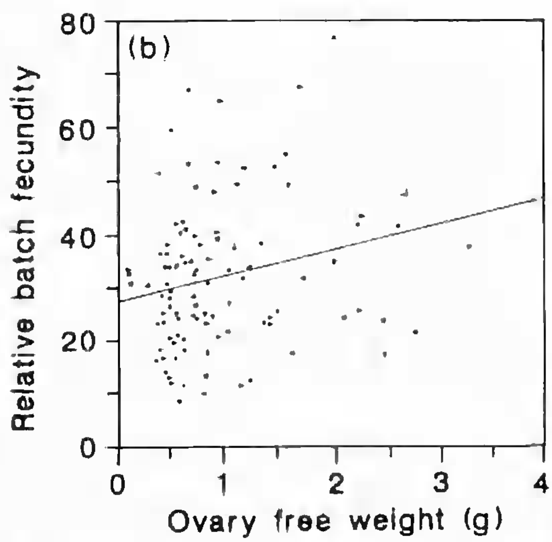


Fig. 9. Relationships between (a) batch fecundity and ovary free body weight ($r^2 = 0.68$, n = 101) and (b) relative batch fecundity and ovary free body weight ($r^2 = 0.04$, n = 101) for female *Atherinosoma microstoma*. Points represent fish collected in September, October and November 1991.

were not affected but high variability, perhaps associated with schooling behaviour of the fish, and low numbers of samples were confounding factors in this analysis.

No major differences were found between sites in growth, size or condition of hardyheads in the Coorong. Growth rates implied from the progression of length modes suggest that *A. microstoma* can achieve a total length of 35 mm in four months, followed by a period of little growth over winter, reaching lengths of 45 mm the following spring, and thereby becoming sexually mature within the first year of life. There was no indication of dwarfism related to high salinity in this population. Maximum sizes for both sexes were similar at all sites in the Coorong and comparable to those found in the Dee Why Lagoon population (Potter *et al.* 1986) and for this species in general (Cadwallader & Backhouse 1983). Maximum total lengths recorded for males were 67 mm (present study) and 66.5 mm (Dee Why Lagoon) and for females 85 mm (present study) and 86.4 mm (Dee Why Lagoon). Fish condition in the Coorong did not differ significantly between sites in March when salinities were high and ranged from 58 at Noonameena to 92 g L^{-1} at Tea Tree Crossing.

Life History, Annual Cycle and Population Structure of Atherinosoma microstoma

The post-breeding decline in larger fish at all sites from December indicates a one-year life cycle. The population showed a numerical dominance of females, and males were also significantly smaller than females. Similar patterns of life history and sexual dimorphism have been found in the population at Dee Why Lagoon, New South Wales (Potter *et al.* 1986) and in atherinids from the Northern Hemisphere (e.g. Gon & Ben-Tuvia 1983). The proportion of female fish in this population appears to decline over the breeding season and a sex ratio of close to one is reached in December. This may be due to differential mortality during the breeding season, or to an increase in the numbers of male fish reaching maturity (>30 mm) as the season progressed. The orange coloration found in male fish appears to be related to reproductive activity and may be under hormonal control.

The marked difference in size between sexes, the prolonged breeding season and the short life cycle of *A. microstoma* may be indicative of a species where sex is determined after conception by environmental factors, such as temperature (Conover 1984). Conover & Kynard (1981) conclusively showed that temperature exerted a direct influence on primary sex differentiation, rather than causing sex specific mortality in the atherinid, *Menidia menidia*. Thus, if eggs spawned in the cooler spring waters develop into females, and eggs spawned in the warmer waters of late summer develop into males, then females would have a longer growing season which would account for their significantly larger size.

Spawning occurred from September to December giving a protracted four month spawning season. This is supported by the large numbers of larvae collected from October to December from all sites. The absence of larvae in the samples, the small GSIs, and the absence of maturing and ripe oocytes in the ovaries during autumn and winter 1991, indicates that this

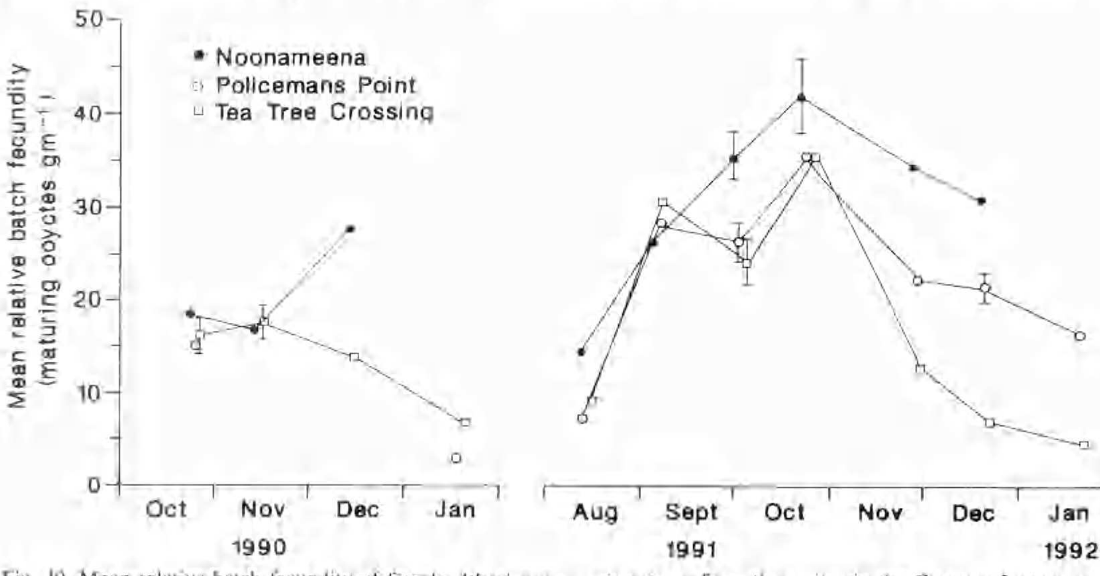


Fig. 10. Mean relative batch fecundity of female *Atherinosoma microstoma* from three sites in the Coorong Lagoon over the 1990-91 and 1991-92 breeding seasons. Points represent mean values of up to 20 fish and vertical lines are one standard deviation each side of the mean. No standard deviation is given when the sample size was less than 10. Only fish with maturing or ripe oocytes were included in the analysis.

species has only one breeding season per year. Mean gonosomatic indices and relative batch fecundities were greatest in November in 1990 and October in 1991, indicating that spawning probably peaked during these months. The later onset of spawning in 1990 is reflected by the later drop in salinities in that year. Thus a reduction in salinity may be one of the environmental variables involved in triggering spawning.

A protracted spawning season may reflect repeated "batches" of eggs being spawned or a lack of population synchrony in gonadal development (DeVlaming 1983). Analysis of egg types shows that oocyte development in *A. microstoma* is "group-synchronous", as at least two size groups of oocytes were present in the ovary of an individual at some time during the reproductive cycle (DeVlaming 1983). This type of oocyte development implies that the whole clutch of ripe oocytes will be shed over a short period (West 1990). Multimodal frequency distributions of oocyte diameters, as found for *A. microstoma* in the Coorong, are characteristic of multiple-spawning fishes (Hempel 1979). The presence of several modes of developing oocytes, the presence of remnant ripe eggs in some ovaries and the decline in the number of maturing eggs per fish as the spawning season progressed indicates that *A. microstoma* is a multiple-spawning fish. Multiple batches of eggs spawned successively within one spawning period have been found in other atherinids including *Menidia menidia* (Conover 1984) and *M. audens* (Hubbs 1976). Protracted spawning is common among atherinids in Australia (e.g. Ivantsoff 1978; Prince & Potter 1983; Potter *et al.* 1986) and in the Northern Hemisphere (e.g. Carpelan 1955, Gon & Ben-Tuvia 1983; Conover 1984; Middaugh & Hemmer 1992). A four month protracted breeding season over spring parallels that found for this species from Dee Why Lagoon, New South Wales, where spawning occurred from August to November (Potter *et al.* 1986).

Influence of Salinity on the Reproductive Performance of Atherinosoma microstoma

A. microstoma is the only recorded Australian atherinid to reproduce in hypersaline waters, with the possible exception of *Craterocephalus pauciradiatus* (Lenanton 1977). The gradient in salinities along the Coorong did not reduce the length of the spawning season in *A. microstoma* as fish were in spawning condition from September to December in both 1990 and 1991 at all sites. Salinities during these periods ranged from 32 g L^{-1} at Noonameena in September 1990 to 74 g L^{-1} at Tea Tree Crossing in December 1990. Salinities are usually at their lowest in the Coorong during spring which may account for the lack of any clear influence of salinity on reproduction in the present study.

Gonad development commences in late winter/early spring at a time when day length and temperature are increasing and these are likely to be the environmental cues for gonad recrudescence. Breeding in spring may be timed to take advantage of seasonal peaks in food availability. In the Coorong, hardyheads feed mainly on zooplankton, in particular ostracods and copepods, and these are most abundant during winter and spring in the Coorong when salinities are relatively low (Geddes 1987). Female hardyheads only develop a portion of their eggs at one time, suggesting that either a physiological or ecological factor (e.g. insufficient food) limits batch fecundity. Relative batch fecundities and gonosomatic indices were lower in 1990 when the growth and performance of *Ruppia tuberosa*, a key aquatic plant in the southern Coorong, was reduced compared with 1991. Other resources including zooplankton may also have been lower. Multiple spawning is a common reproductive strategy among small fish species and maximises the numbers of eggs a small fish can produce (Potter pers. comm.). In addition, *A. microstoma* may be able to adjust batch size in response to environmental conditions. Such a strategy would allow hardyheads to exploit both longer reproductive seasons and better quality seasons. This strategy would require the initiation of more oocytes than would be expected to be shed in most years.

The Role of Atherinosoma microstoma *in the Coorong*

Atherinids are an important component of the biomass of small fish of many aquatic ecosystems, including Bardawil Lagoon (Ben-Tuvia 1984), Laguna Madre (Hedgpeth 1967), Hamelin Pool (Lenanton 1977), Peel Harvey estuary (Potter *et al.* 1983) and the Swan-Avon River system (Prince & Potter 1983). *A. microstoma* is a prominent component of the Coorong ecosystem, in particular as a major food item for selected piscivorous water birds (Paton 1982). High and fluctuating salinities along the Coorong did not have a marked effect on the population ecology or reproductive behaviour of *A. microstoma* and no significant differences in relative batch fecundities were found between sites that differed in salinity within a year. Thus, *A. microstoma* appears to be well adapted to hypersaline conditions and future small changes in salinity would not be expected to affect hardyheads in the Coorong. However, their food supply may be affected by salinity. Future studies should be directed toward the diet of *A. microstoma* in the Coorong and the factors that might limit these resources.

The agricultural areas of the Upper South East of South Australia suffer from dryland salinization and seasonal inundation of lowlying areas with surplus surface water. There are proposals to drain some of this surface water and possibly groundwater into the South Lagoon of the Coorong (Upper South East Dryland Salinity and Flood Management Plan Steering

Committee, 1993[3]). Such inputs of fresh or brackish water may disrupt the seasonal fluctuations in salinity which are an important feature of the Coorong and which may act as a partial cue to spawning in *A. microstoma*. Other consequences of the inputs, such as an increase in water depth and consequent reduction in the exposure of the highly productive mud flats, or a rise in nutrient or heavy metal concentrations may also affect the food chains in the Coorong supporting *A. microstoma* and in-turn piscivorous birds. Consideration needs to be given to the role of hardyheads in the Coorong ecosystem in future management proposals.

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